

Computerized decision support system improves fluid resuscitation following severe burns: An original study*

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Objective: Several formulas have been developed to guide resuscitation in severely burned patients during the initial 48 hrs after injury. These approaches require manual titration of fluid that may result in human error during this process and lead to suboptimal outcomes. The goal of this study was to analyze the efficacy of a computerized open-loop decision support system for burn resuscitation compared to historical controls.

Design: Fluid infusion rates and urinary output from 39 severely burned patients with >20% total body surface area burns were recorded upon admission (Model group). A fluid-response model based on these data was developed and incorporated into a computerized open-loop algorithm and computer decision support system. The computer decision support system was used to resuscitate 32 subsequent patients with severe burns (computer decision support system group) and compared with the Model group.

Setting: Burn intensive care unit of a metropolitan Level 1 Trauma center.

Patients: Acute burn patients with >20% total body surface area requiring active fluid resuscitation during the initial 24 to 48 hours after burn.

Measurements and Main Results: We found no significant difference between the Model and computer decision support system groups in age, total body surface area, or injury mechanism. Total crystalloid volume during the first 48 hrs post burn, total crystalloid intensive care unit volume, and initial 24-hr crystalloid intensive care unit volume were all lower in the computer decision support system group. Infused volume per kilogram body weight (mL/kg) and per percentage burn (mL/kg/total body surface area) were also lower for the computer decision support system group. The number of patients who met hourly urinary output goals was higher in the computer decision support system group.

Conclusions: Implementation of a computer decision support system for burn resuscitation in the intensive care unit resulted in improved fluid management of severely burned patients. All measures of crystalloid fluid volume were reduced while patients were maintained within urinary output targets a higher percentage of the time. The addition of computer decision support system technology improved patient care. (Crit Care Med 2011; 39:2031–2038)

KEY WORDS: automated systems; burn care; burn resuscitation; computer decision support; crystalloid infusion; information technology

The promulgation of computer decision support systems (CDSSs) has not been as widespread in medicine as in other areas that depend on information tech-

nology. The critical care arena has been typically recalcitrant to accept computers within the patient care environment. Automating complex clinical decision-making paradigms, coupled with regulatory and technical limitations, is just one of the hurdles that has kept advanced information systems from being deployed beyond simple documentation roles. However, as patient care continues to evolve into using additional devices, sensors, and information sources related to the patient condition, the need for automation and decision support in this environment becomes critical. Similarly, as patient care becomes more specialized while the number of primary care personnel is being reduced, having automated systems that have the skills and knowledge of expert providers becomes increasingly important.

An example of the need for decision support technology is the burn critical care environment. In this arena, effective initial management of severe burns is critical for minimizing both resuscitation-related morbidity and mortality.

Each year, approximately 40,000 adult patients with severe burns require hospitalization, approximately 4,000 of whom die of their injuries (1–3). Burn management requires specialized expertise and treatment options that may not normally be available at nonburn centers. In addition, personnel trained in burn care must provide prompt initialization of fluid therapy coupled with continuous attentive care at admission to the intensive care unit (ICU) (4). Appropriate fluid titration during the initial resuscitation period of acute burn is vital and has been the cornerstone of effective burn care (4). Standard pathophysiologic response to a thermal injury results in a burn-induced intravascular fluid deficit featuring a substantial plasma volume deficit during the initial 48 hrs post burn, which engenders hypovolemic shock and generalized edema formation (4). These include a principal fluid shift into the surrounding interstitial space (i.e., third-spacing) that has to be treated to avoid burn shock conditions (5–6).

*See also p. 2178.

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Effective early fluid management in these patients has been shown to reduce poor outcomes and decrease complication rates (7–15). Similarly, delayed or inadequate fluid resuscitation is associated with increased morbidity and mortality rates (8). Most providers strive to standardize resuscitation to maintain adequate urinary output (UOP) volumes as a proxy to cardiac output by continued hourly titration of crystalloid fluids. Calculation of initial infusion rates is typically based on the Brooke or the Parkland formulas (16–18) that define total volume requirements over the initial 24 hrs after burn, with a prescribed goal ranging between 2 mL/kg/total body surface area (TBSA) and 4 mL/kg/TBSA and target UOPs between 30 and 50 mL/hr. This formula includes giving half the required fluid in the initial 8 hrs of resuscitation (18–21). However, burn studies reported in the literature consistently report over-resuscitation of burn patients with values that are consistently higher than the maximum 4 mL/kg/% TBSA directed by the Parkland rate. A meta-analysis of 31 burn studies demonstrated that 86% reported mean fluid volumes exceeding the Parkland estimates (22).

One solution is the use of information systems coupled with decision support technology to provide recommendations for fluid volumes based on measured biological responses in a similar population of burned patients. These recommendations consider the patient's own responses to assist care personnel during the resuscitation phase. CDSSs have been successfully used in the clinical setting for several years (23–24). Using decision support technology, we developed a novel CDSS for resuscitation of patients with acute burns (TBSA >20%) during the initial 48 hrs after burn. The system implements an open-loop concept that provides recommendations to assist users in making decisions during patient care. These recommendations are then used by licensed providers to help them make better treatment decisions when determining fluid rates over the next hour. The CDSS was deployed in our burn ICU in November 2007 and has become our current practice for all new patients admitted to our burn ICU. The goal of this study was to analyze the efficacy of the CDSS in burn resuscitation compared to historical controls.

MATERIALS AND METHODS

CDSS Development

We obtained local approval from the Brooke Army Medical Center Institutional Review Board for a study to collect and analyze data from 40 consecutive adult patients with $\geq 20\%$ TBSA burns admitted to our burn ICU from November 2004 to February 2007. A computerized digital acquisition system was used to capture UOP volumes from a digital urimeter (Bard Criticare, Murray Hill, NJ) during the initial 48-hr resuscitation. One subject was dropped from the study because of missing data, resulting in a total of 39 patients used for model development. Research personnel recorded crystalloid infusion rates manually at the top of each hour. Fluid intake and output rates were analyzed for all patients to determine average fluid rates at each hour, rate of change from previous hour, and percentage of time within acceptable UOP targets of 30 to 50 mL/hr. Mean fluid rate and UOP were computed for each hour after burn for up to 48 hrs to determine the expected mean fluid rate for the cohort. A set of curve-fit methods was used on both the infusion and the UOP data sets to derive their best-fit function. A fluid-response equation was derived for estimating average crystalloid fluid requirements for each milliliter of UOP generated at each hour. Colloid use during resuscitation in the first 24 hrs is not standard practice in our unit and was not considered for model development in this instance (the model is based on titration of hourly lactated Ringer's solution). A target UOP rate of 40 mL/hr was used for model development (average of upper and lower bounds of 30 mL/hr and 50 mL/hr). Equation modifiers for TBSA and weight were developed to adjust recommendations based on these additional parameters. Final CDSS model equations were programmed into a computer algorithm to generate recommendations for crystalloid titration for each hour. The CDSS was developed using the Java (Sun Microsystems, Palo Alto, CA) programming language and deployed on a computer system within each room in our ICU.

Analysis

Historical control data from the 39 patients enrolled during model development was compared with data from patients on CDSS admitted from November 2007 to January 2009 and analyzed for improvements in crystalloid fluid management and outcomes. During this period, 66 consecutive patients were resuscitated with the CDSS during the initial 48 hrs post-ICU admission. We included patients on the CDSS who had at least 24 hrs of recommendations from the software for this analysis. Patients with <24 hrs of recommen-

dations because of clinical complications, death, or other factors were excluded. The control cohort included only patients who survived for the initial 24 hrs postadmission and had undergone at least 24 hrs of fluid resuscitation. Student's *t* tests and chi-square tests were used to compare variables using the SPSS Version 16 (SPSS, Chicago, IL) statistical analysis system. Left-skewed variables that were not normally distributed underwent logarithmic (log) transformation to achieve normality. Other nonparametric variables were compared by using Mann-Whitney *U* tests. Analyzed variables included mortality, 24-hr crystalloid volume, 48-hr crystalloid volume, prehospital volume, 48-hr mL/kg volume, 48-hr mL/kg/TBSA volume, and percentage of time within target UOP. Analysis of outcomes included ICU-free days (IFDs), and ventilator-free days (VFDs). IFDs and VFDs were defined as the number of each individual's total days subtracted from the cohort mean.

RESULTS

System Development

Results of overall total crystalloid infusion per hour showed a continuous decay pattern over the initial 48 hrs of resuscitation (Fig. 1A). An exponential decay function given by $f(hpb) = Xe^{(-Y \times hpb)}$ had the best fit for the crystalloid infusion rates during this time, with *X*, *Y* representing the function coefficients of decay and *hpb* representing hours post burn. The UOP values had a linear function fit to the data of the form $f(hpb) = M \times hpb + N$, with *M*, *N* representing the linear coefficients of the function (Fig. 1B). The exponential decay function model suggested the need for larger infusion rates at the beginning of the resuscitation period to achieve the same UOP than in later hours. The ratio of fluid infusion to the UOP for each hour post burn is therefore represented by the nonlinear ratio of $f(\text{fluid_ratio}) = \text{fluid_rate}/\text{UOP} = ()Xe^{(-Y \times hpb)}/(M \times hpb + N)$ for each postinjury hour given by *hpb*. This equation shows the expected fluid rate per milliliter of UOP of the model cohort. For algorithm and software implementation, the function was divided into three phases (I, II, III) by dividing the maximum amount of fluid predicted into three equal fluid rate sections. The three phases corresponded to periods when patient fluid needs changed from a high volume during the first period to the minimum rate at the end of the 48 hrs. They allowed the system to reduce fluid change recommendations as the patient became more stable and prevented the

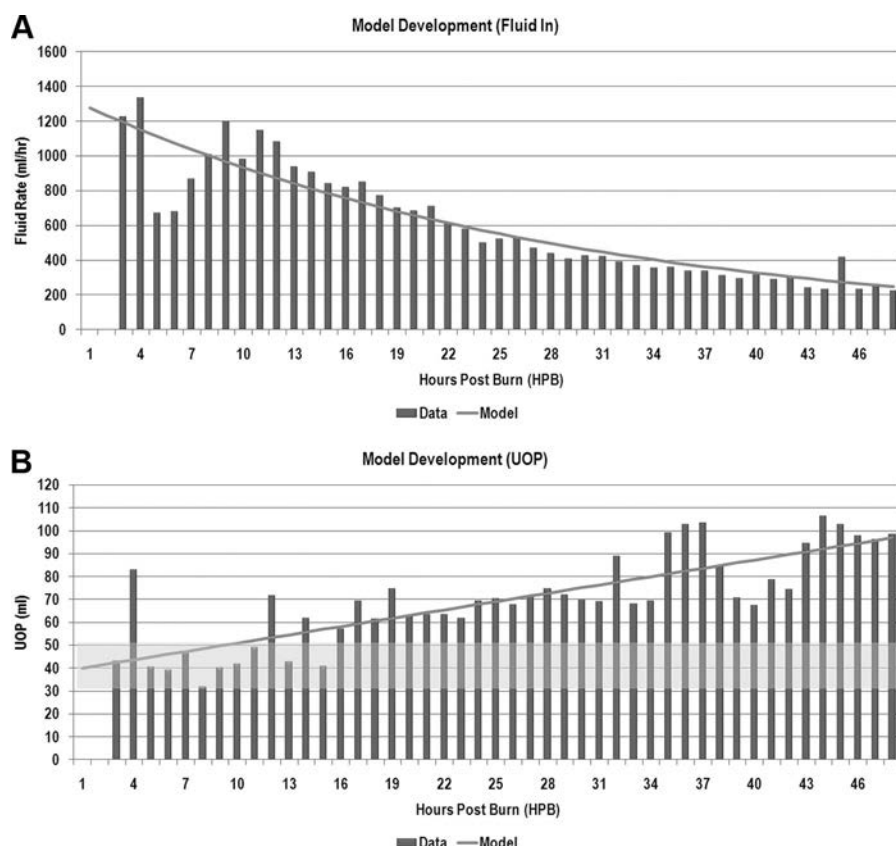


Figure 1. A, Average crystalloid infusion rates captured from patient data (*bar*) compared with exponential decay model (*line*). B, Average urine output (UOP) volume captured from patient data (*bar*) compared with linear model (*line*).

system from dramatic changes in recommendation rates as the patient moved from one phase to another. Phase I included hours 0 to 13 after burn; Phase II, hours 14 to 33 after burn; and Phase III, hour 33 and greater. For each phase, the average rate of infusion change at each hour was calculated with a corresponding set of constants. Using these constants and the previous hour's infusion rate, we derived a new formula for computing the amount of crystalloid infusion to change from the previous hour to bring the patient down to a target level given the expected response and hour postburn.

To further compensate for intra-patient variations in TBSA and weight, we implemented a set of generalized logistic curves as the modifiers to the base fluid rate model equation. These provided a patient-specific modifier based on the patient's weight and TBSA given by the equation $Y = A + C/(1 + Te^{-B(X-M)})^{1/T}$, where A , B , X , M , and T represent coefficients defining the logistic curve for value Y (TBSA or weight). Coefficients for these two equations were chosen based on the distribution of TBSA and weight of

the patient model cohorts and reflect deviations of TBSA and weight from the model (i.e., patients with TBSA > model average will require additional fluid). The resulting equations are independent of hours post burn and represent a constant used to further modify the results of the model equation based on the patient's TBSA and weight. A final burn modifier coefficient was included to reduce the effect of large variations in fluid recommendations given by the function $BM = I_{t-1}/(TBSA \times 10)$, where BM is the burn modifier coefficient and I_t is the crystalloid infusion at hour postburn t . Results of these modifiers were multiplied by the previous hour's rate and used as the final crystalloid recommendation for the next hour or half-hour rate. To guarantee minimal change to the recommended infusion as the patient's UOP approaches the target of 40 mL/hr, we used an additional weighting factor based on an inverted Gaussian function as an additional filter. This equation, minimized at the target fluid rate, is given by $G = 1 - e^{-(UOP-40)^2/25}$ to further limit changes to fluid rates as the patient approaches

Table 1. Rule of 10 for determining initial crystalloid resuscitation volume

Weight (kg)	Initial Rate (mL/hr)
≤80	% Total Body Surface Area × 10
>80	% Total Body Surface Area × 10 + 100 mL for every 10 kg over 80

the 40-mL/hr UOP target. Additionally, because changes in UOP at each hour may be driven by several factors in addition to renal function and fluid volume, a UOP projection formula was implemented to calculate the expected UOP for the next hour. This formula is based on a projection of the last three nonzero UOP values using a linear estimator function to estimate the next hour's UOP. The linear estimator fits a line to the last three UOP measures to reduce the amount of noise in the UOP results due to other factors not related to resuscitation. The resulting projected UOP value constituted the UOP input into the recommendation calculations. Initial recommendations (in milliliters per hour) of crystalloids within the model were based on the Rule of 10 approach (Table 1), which provides a simple and rapid derivation of the initial fluid rate by multiplying the TBSA by a factor of 10 with additional fluid volume for overweight patients over 80 kg (25).

CDSS deployment consisted of a dual-screen computer system running the Java run-time environment. Normal configuration for a resuscitation patient used the top computer screen to run the main CDSS application and the bottom screen to run the Essentris electronic charting system (Clinicomp, San Diego, CA). UOP data were manually input into the system from the digital readout of the electronic urimeter (Bard Criticare, Murray Hill, NJ). Final lactated Ringer's rates were adjusted on the fluid infusion pumps (Hospira Plum A+, Hospira, Lake Forest, IL).

The system included several characteristics that allow for ease of use and integration into the nursing and critical care workflow environment, including the following:

- **Network deployability.** CDSS design and implementation were based on a centralized application system that resides on a common file server within our institute. The CDSS application is automatically downloaded and executed on the bedside computer in the

ICU when required through a standard shared network drive available to all ICU computers.

- **Java implementation.** The CDSS was written in the Java programming language to allow the application to execute independently of the underlying hardware or computer system.
- **Link into electronic charting.** The CDSS provided a link into the electronic charting system for patient updates and data verification. These data included additional fluids and physiologic parameters of the patient.

Workflow of the CDSS was incorporated into the critical care procedures required during patient admission and subsequent resuscitation. The main CDSS application screen is composed of a two-panel window application. Warning rules were implemented both graphically and verbally when the patient reached 200 mL/kg and 250 mL/kg in the last 24 hrs. Additional markers for 2 mL/kg/TBSA and 4 mL/kg/TBSA were depicted graphically on this window. The bottom application panel was used for the intake/output table and fluid balance display. The lower window panel was used for data input and hourly graphing displays. Hourly input was done through a table interface where users were able to input all fluid values given to the patient for each hour of the resuscitation. An hourly graphing system provided a fluid balance view showing infusion fluid rates, recommendations, and UOP values for each hour. Fluids were color coded according to the fluid type and further broken down by prehospital and ICU rates. UOP values were color coded according to where they fell within the specified range of 30 mL/hr to 50 mL/hr. Values higher than 50 mL/hr were coded red, whereas values below the range were coded yellow and green when on target.

Termination of the CDSS is determined by a combination of clinical practice guidelines and built-in system rules including the following:

- Termination has been requested by the attending physician.
- Patient has been on maintenance rate (125 mL/hr) for 6 hrs (but not <24 hrs).
- Patient has been stable at 48 hrs post burn.
- Patient has been transferred to surgery.

System exit rules are treated as recommendations and are followed at the discretion of the provider. Additionally, a

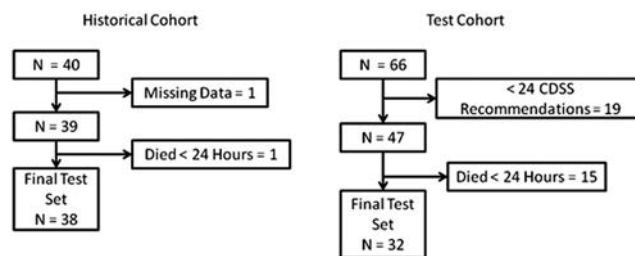


Figure 2. Consort diagram for test cohorts. CDSS, computer decision support systems.

Table 2. Demographics and injury comparison between control and computer decision support system cohorts

Parameter	Control (n = 38)	Computer Decision Support System (n = 32)	p
Age (years)	50 ± 21	44 ± 16	.18
Weight (kg)	88 ± 24	87 ± 23	.83
Gender	Male: n = 28, 74%	Male: n = 25, 78%	.67
% Total Body Surface Area ^a	40 ± 19	39 ± 16	.94
% Full Thickness ^a	11.5 (QI: 0, 11.50, 40.75)	9 (QI: 0, 9, 16.75)	.07
Inhalation Injury (%) ^b	Positive: n = 11, 29%	Positive: n = 10, 31%	.83

QI, quartiles (25%, 50%, 75%).

^aVariables are not normal. Log transform used for Student's *t* test comparison. ^bmeasured via a fiber optic bronchoscopy test.

patient may be restarted on the CDSS system after a prolonged break at the request of the attending physician (i.e., after returning from surgery) if needed if the patient is still within the 48-hr resuscitation window.

The system incorporated a set of rules and limits based on a set of consensus definitions agreed to by a clinical panel of burn care providers. Recommendations from the CDSS outside normal institute guidelines required approval from a licensed care provider. A real-time system clock prompted the user at the recommended time points during the resuscitation (every 60 or 30 mins) for data from the current infusion pumps and electronic urimeter.

The CDSS generated recommendations for new lactated Ringer's rates automatically once the user input and verified the required data. If the user chose not to accept the new fluid rate recommendations, the CDSS prompted the user to document the reason for deviating from the recommended system rate. All user interactions with the system were saved to the centralized database for review and documentation.

Analysis Results

From initial deployment through January 2009, 32 patients were resuscitated with the CDSS with at least 24 hrs of recommendations during the initial 48 hrs postburn. These were analyzed

against 38 historical control patients (model development cohort) that met criteria for inclusion collected between November 2004 and February 2007 (Fig. 2). Both the CDSS and the control cohorts had values for TBSA, age, weight, gender, and rate of inhalation injury that were not statistically different (Table 2). A log transform was used on the TBSA and full-thickness continuous variables to normalize them before analysis. The CDSS patients had statistically lower resuscitation volume over the initial 48 hrs (including prehospital, emergency department, and ICU volumes of crystalloids) (Fig. 3A). Total fluid volume over 48 hrs (prehospital and resuscitation) was reduced from 26,309 ± 14,454 mL to 15,605 ± 5707 mL (*p* < .05) (Fig. 4A). Prehospital crystalloid infusion volume was significantly different between the two groups; controls received an average of 4993 ± 4081 mL vs. 3222 ± 2290 mL for the CDSS group (*p* < .05). When prehospital volume was eliminated from the analysis, the total of crystalloids post-ICU admission over the initial 24 hrs was still reduced from 14,973 ± 10,681 mL to 9679 ± 4776 mL (*p* < .05). Additionally, total crystalloid volumes after ICU admission over the entire resuscitation were reduced from 21,316 ± 12,974 mL in the control to 13,088 ± 5644 mL in the CDSS group (*p* < .05).

Ratio comparisons resulted in CDSS patients also having lower mL/kg and mL/kg/TBSA values during the resuscitation period (Fig. 4, B and C). CDSS patients had

reduced mL/kg/TBSA from 6.5 ± 4.1 mL/kg/TBSA to 4.2 ± 1.8 mL/kg/TBSA over the initial 24 hrs after burn ($p < .05$). Ratios were reduced from 7.3 ± 5.6 mL/kg/TBSA

to 4.6 ± 2.5 mL/kg/TBSA over the entire resuscitation period ($p < .05$). UOP values were compared at each hour during the initial 48 hrs to determine whether patients met target ranges of 30 to 50 mL/hr rates. CDSS patients had higher rates of UOP values within target than control. CDSS patients achieved a percentage target in UOP range an average of $31\% \pm 16\%$ over 48 hrs compared to $23\% \pm 13\%$ for the control group ($p < .05$) (Fig. 3B).

Results from the hour-by-hour algorithm performance resulted in higher UOP rates in target (30 to 50 mL/hr) when providers did not deviate >100 mL/hr from the CDSS recommendations compared with deviations >100 mL/hr during the initial 24 hrs post burn ($p < .05$) (Fig. 5). As deviations from the CDSS recommendation increased, the frequency target percentage in UOP target range was further decreased. UOP hour-by-hour analysis of variance using Levene's test for equality of variances also showed a significant difference between the two groups, with the control group showing more variability across the resuscitation time vs. the CDSS group (Fig. 6).

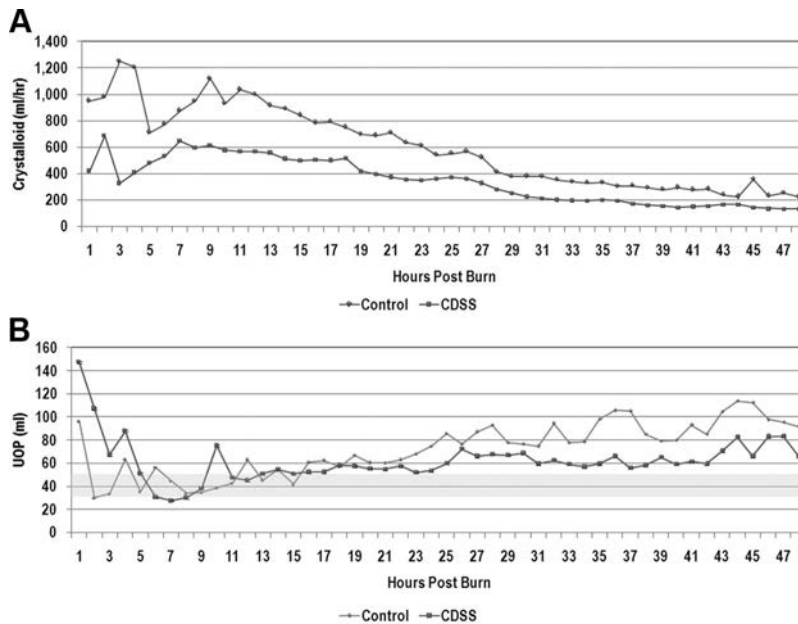


Figure 3. A, Comparison of infusion rates between control and computer decision support systems (CDSS) patients. B, Volume comparison of urine output (UOP) between control and CDSS patients.

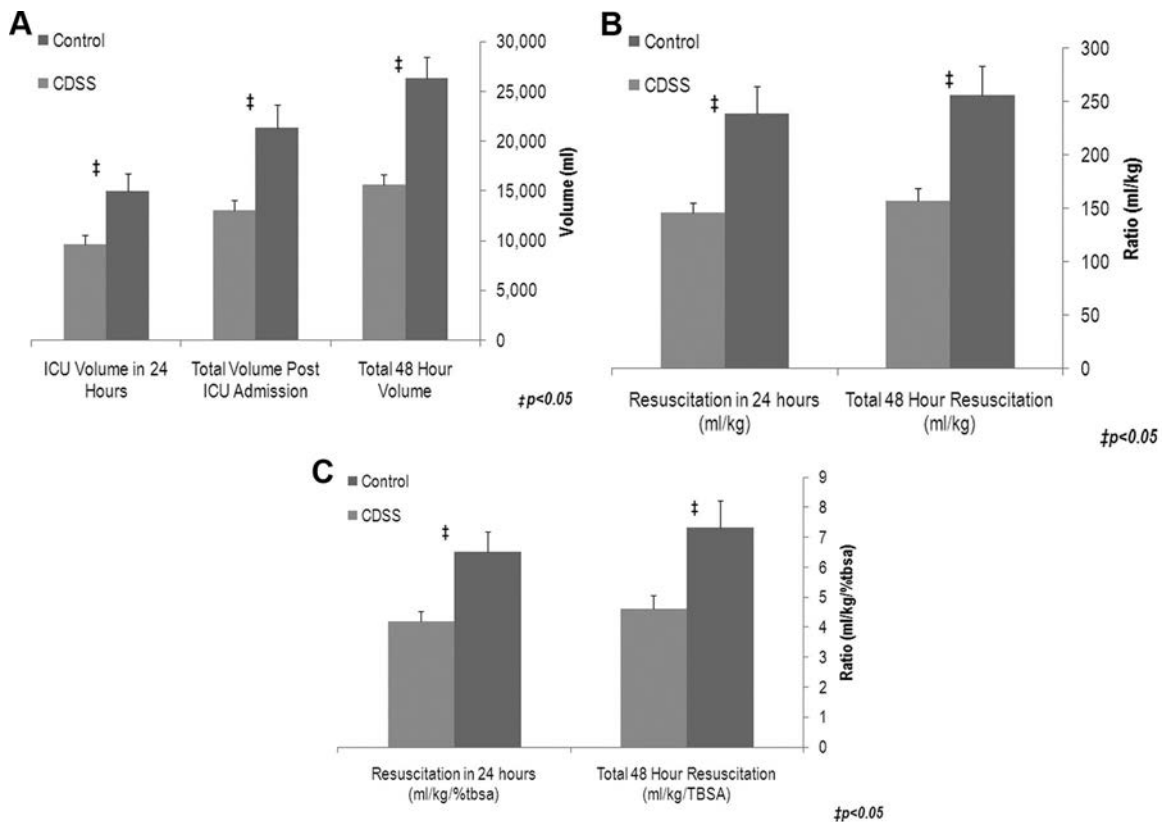


Figure 4. A, Volume comparison between the control and the computerized decision support system (CDSS) groups. B, Total resuscitation (mL/kg) comparison between control and the CDSS. C, Total resuscitation (mL/kg/% total body surface area [TBSA]) comparison between control and CDSS. ICU, intensive care unit.

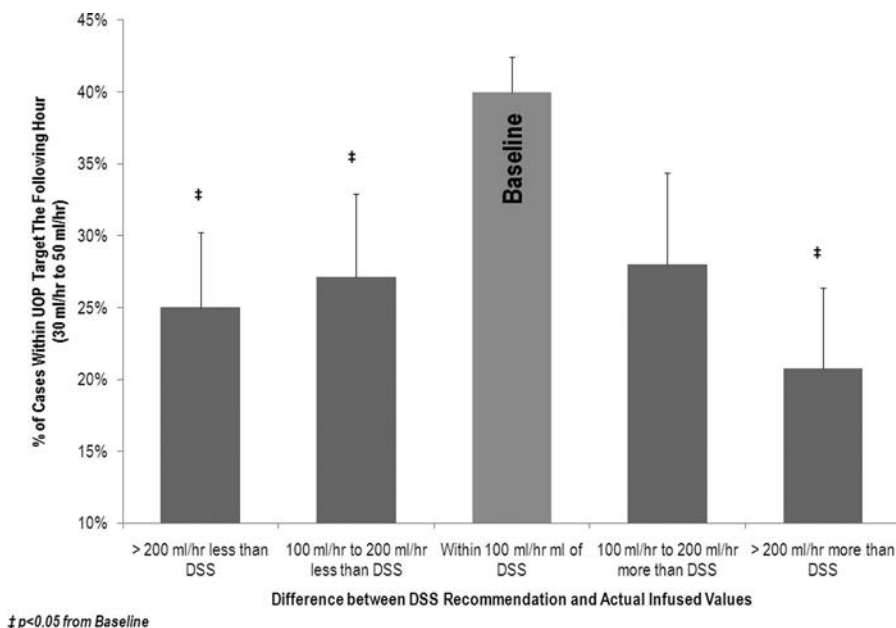


Figure 5. Urine output (UOP) targets as a function of the difference between recommendations of the computerized decision support system (DSS) and actual infused fluid volumes.

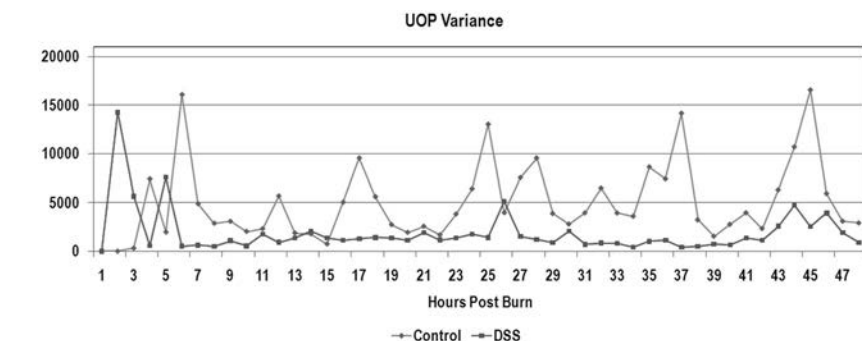


Figure 6. Comparison of hour-by-hour urinary output (UOP) variance between control and computerized decision support system (CDSS) patients.

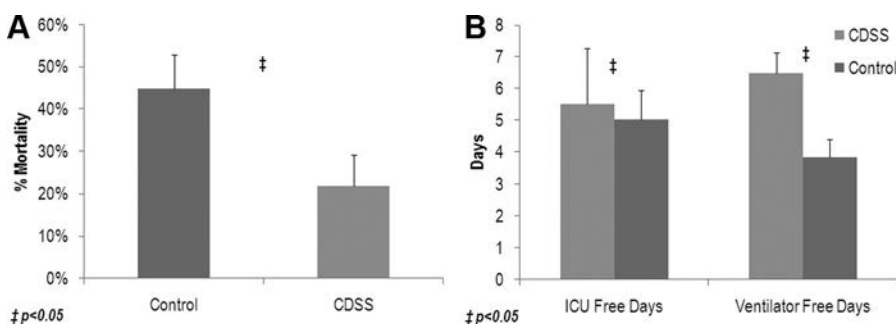


Figure 7. A, Mortality comparison between control and computerized decision support system (CDSS) patients. B, Outcomes comparison between control and CDSS patients. ICU, intensive care unit.

The CDSS group had a lower mortality than the historical cohort (29% vs. 44%) ($p < .05$) (Fig. 7A). Mean ventilator and ICU days for the two groups were 13 days and 30 days, respectively. These values were used to derive the VFDs and IFDs for comparison. Mean VFDs were also higher in the CDSS group (6.5 ± 5.5 vs. 3.8 ± 5.2) ($p <$

$.05$) (Fig. 7B). IFDs were not different between groups.

DISCUSSION

The need for fluid volume therapy for burn shock has been recognized for many years (26–27). Baxter and Shires (18), for

example, showed in 1968 that successful resuscitation could be accomplished with a formula consisting of 4 mL/kg per TBSA of lactated Ringer's solution in the initial 24 hrs postburn. Subsequently, Pruitt et al (12) provided a modification to the Brooke formula of 2 mL/kg per TBSA in which albumin was eliminated during the first 24 hrs. However, recent studies have suggested that these formulas will not accurately determine the amount of fluid needed for resuscitation, and do not accurately reflect the total volume required by the patient (28). Similarly, the issue of fluid creep has been documented in several studies, showing that fluid volumes have been increasing constantly over the last several years (29–31). However, over-resuscitation has the potential to increase morbidity and life-threatening complications, such as abdominal compartment syndrome. On the other hand, not providing the patient with sufficient fluid may also increase rates of serious problems by not addressing the inherent intravascular fluid deficit associated with the burn injury. Therefore, effective resuscitation becomes a challenge when patients have to be kept to an appropriate fluid balance regimen that will mitigate possible complications from too much or too little fluid. For the clinician or care provider, one of the main challenges for appropriate fluid management may be due to the complexity of the resuscitation guidelines themselves. Depending on care providers to calculate and derive the necessary fluid delivery rates for each hour while providing appropriate care to major burn injuries may be problematic in many instances. This issue becomes increasingly critical if the patient is being treated at a regional hospital or nonburn facility. Furthermore, when coupled with mass casualty situations, the workload and requirements for care of multiple large burns may overwhelm many centers.

One of the advantages of using our CDSS is the ability to better model the expected fluid response from burns such that fluid titration is more accurate and effective throughout the resuscitation phase compared to standard manual approaches that divide the injury response into two broad phases. Phase 1 is the initial 8 hrs, when it is assumed that the patient will require the most fluid, and phase II is the next 16 hrs of the resuscitation, where much less fluid is given. However, these approaches assume a constant physiologic response that is fixed on an 8-hr and 16-hr response pe-

riod. Physiologically, this response is not likely to occur. Our experience using our CDSS has shown that patients not only vary widely but also require a continuous increasing need for fluid that is maximized during the initial 13 hrs postburn in addition to requiring fluid at a constantly decreasing rate thereafter. Plotting the infused fluid during the initial 24 hrs shows a continuum of fluid need that can only be modeled as a complex set of mathematical equations. Unfortunately, implementing such a system of continuous fluid titration cannot easily be done manually and requires the use of computer technology capable of implementing such a complex resuscitation strategy.

When comparing the rates of UOP within target, the CDSS does achieve a higher UOP on target (31%) than the control group (23%). However, even though this improvement is statistically significant, clinically it is still a marginal increase in target percentages. Overall, patients have a UOP >50 mL/hr in many cases. One explanation for this low increase can be seen in the difference between the recommendations by the CDSS and the actual infusion rates given by the healthcare providers. On average, users are infusing more crystalloid than the system recommended. In accordance with implementation of this system, fluid rates are strictly provided as a recommendation; it is expected that the provider use clinical judgment when appropriate and provide a documented reason for not following the system recommendation. To better understand the actual performance of the algorithm, we need to compare the instances where the providers accepted the system recommendation vs. using their own judgment. In this case, UOP rates within target were up to 20% higher when providers followed the system recommendations. Furthermore, these results reveal that as the differences between recommendations and actual rates diverge, percentages of UOP in target will tend to also decrease. Based on these results, we can conclude that the computerized algorithm will increase levels of compliance in burn injury and result in better care for patients, and also may explain the increased fluid administration that led to many of the UOP values missing the recommended target rate upper limit of 50 mL/hr.

Furthermore, results from this analysis show promise that the use of the CDSS may provide an improvement in overall resuscitation management of

acute burns in terms of fluid administration and hospitalization outcomes (e.g., VFDs, mortality). When looking at all measures of fluid use, the CDSS significantly reduces all fluid volumes and provides better fluid management during the 48-hr resuscitation period. This is particularly apparent during the initial 13 hrs in which large-volume shifts are possible while trying to maintain adequate UOPs. Even though there are other confounders in this study, these results show that an improvement in mortality may be attributed to the use of the CDSS. However, it can be argued that the use of the CDSS may not be completely responsible for this improvement.

Overall, when all variables are examined, it can be argued that the use of the CDSS provides an improvement in the resuscitation of severely burned patients. It allows care providers to achieve better resuscitation results and may provide a means for allowing nonburn users to effectively resuscitate severely burned patients. When coupled with effective clinical practice guidelines within our burn center, the CDSS provides an effective adjunct to burn care that resulted in improved outcomes. The use of decision support technology can effectively assist in the care of burns without supplanting the expertise available at the bedside.

CONCLUSIONS

Current resuscitation approaches based on standard formulas are typically only used as guidelines and lead to significant inconsistencies and variability between healthcare providers and patients. Using a mathematical approach to develop a resuscitation-response model, we developed an algorithm to provide users with crystalloid infusion recommendations during the initial 48 hrs of burn resuscitation. The CDSS was implemented as the standard clinical practice in our unit and compared against historical controls to assess for any improvements in the resuscitation management of burn patients. This study showed that the CDSS was able to maintain patients on UOP target a larger percentage of the time, while achieving lower fluid infusions compared to our control cohort. Patients on the CDSS system had statistically lower mL/kg and mL/kg/TBSA values than controls, as well as reduced overall fluid requirements at both 24 and 48 hrs postburn. Additionally, the CDSS achieved the target UOP a greater percentage of the time. Finally, results suggest that using our

CDSS, patients had a significantly lower mortality and increased VFDs and IFDs. This study provides an example of patient healthcare improvement using information and decision support technology.

REFERENCES

1. Ahrens M: An overview of the U.S. fire problem. Quincy, MA, National Fire Protection Association, 2007
2. National Burn Repository 2005 Report. American Burn Association, 2006
3. Karter M: Fire loss in the United States. Quincy, MA, National Fire Protection Association, 2008
4. Herndon DN (Ed): Total Burn Care. Third Edition. Philadelphia, PA, Saunders Elsevier, 2007
5. Oliver RI Jr: Burns, Resuscitation and Early Management. Available at: <http://www.emedicine.com/plastic/topic159.htm>. Accessed July 28, 2009
6. Kramer GC, Lund T, Herndon DN: Pathophysiology of burn shock and burn edema. In: Total Burn Care. Second Edition. Herndon DN (Ed). Philadelphia, PA, Saunders Elsevier, 2002, pp 78–87
7. Azzopardi EA, McWilliams B, Iyer S, et al: Fluid resuscitation in adults with severe burns at risk of secondary abdominal compartment syndrome—an evidence based systematic review. *Burns* 2009; 35:911–920
8. Barrow RE, Jeschke MG, Herndon DN: Early fluid resuscitation improves outcomes in severely burned children. *Resuscitation* 2000; 45:91–96
9. Wolf SE, Rose JK, Desai MH, et al: Mortality determinants in massive pediatric burns. An analysis of 103 children with > or = 80% TBSA burns (> or = 70% full-thickness). *Ann Surg* 1997; 225:554–565; discussion 565–569
10. Kirkpatrick AW, Ball CG, Nickerson D, et al: Intraabdominal hypertension and the abdominal compartment syndrome in burn patients. *World J Surg* 2009; 33:1142–1149
11. Ivy ME, Atweh NA, Palmer J, et al: Intraabdominal hypertension and abdominal compartment syndrome in burn patients. *J Trauma* 2000; 49:387–391
12. Pruitt BA Jr: Fluid and electrolyte replacement in the burned patient. *Surg Clin North Am* 1978; 58:1291–1312
13. Brandstrup B, Tønnesen H, Beier-Holgersen R, et al: Effects of intravenous fluid restriction on postoperative complications: Comparison of two perioperative fluid regimens: A randomized assessor-blinded multicenter trial. *Ann Surg* 2003; 238:641–648
14. Tricklebank S: Modern trends in fluid therapy for burns. *Burns* 2009; 35:757–767
15. Arieff AI: Fatal postoperative pulmonary edema: Pathogenesis and literature review. *Chest* 1999; 115:1371–1377
16. Advanced Burn Life Support Course (ABLS): Instructor's Manual. Chicago, IL, American Burn Association, 2001
17. Warden GD: Fluid resuscitation and early

- management. In: Total Burn Care. Second Edition. Herndon DN (Ed). Philadelphia, PA, Saunders Elsevier, 2002, pp 88–97
18. Baxter CR, Shires T: Physiological response to crystalloid resuscitation of severe burns. *Ann NY Acad Sci* 1968; 150:874–894
 19. Engrav LH, Colescott PL, Kemalyan N, et al: A biopsy of the use of the Baxter formula to resuscitate burns or do we do it like Charlie did it? *J Burn Care Rehabil* 2000; 21:91–95
 20. Kemalyan N, Dimick PL, Heimbach DM, et al: The Baxter Formula 1995. *Proc Am Burn Assn* 1996; 28:72
 21. Shah A, Kramer GC, Grady JJ, et al: Meta-analysis of fluid requirements for burn injury 1980–2002. Abstr. *J Burn Care Rehabil* 24: S118
 22. Salinas J, Drew G, Gallagher J, et al: Closed-loop and decision-assist resuscitation of burn patients. *J Trauma* 2008; 64:S321–S332
 23. Clinical Decision Support Systems. Available at: http://en.wikipedia.org/wiki/Clinical_decision_support_system. Accessed July 28, 2009
 24. Coiera E: Guide to Health Informatics. Second Edition. London, Oxford University Press, 2003
 25. Chung KK, Salinas J, Renz EM, et al: Simple derivation of the initial fluid rate for the resuscitation of severely burned adult combat casualties: In silico validation of the rule of 10. *J Trauma* 2010; 69:S49–S54
 26. Evans EI, Purnell OJ, Robinett RW, et al: Fluid and electrolyte requirements in severe burns. *Ann Surg* 1952; 135:804–817
 27. Reiss E, Stirman J, Artz C, et al: Fluid and electrolyte balance in burns. *JAMA* 1953; 152:1309–1313
 28. Cartotto RC, Innes M, Musgrave MA, et al: How well does the Parkland formula estimate actual fluid resuscitation volumes? *J Burn Care Rehabil* 2002; 23:258–265
 29. Friedrich JB, Sullivan SR, Engrav LH, et al: Is supra-Baxter resuscitation in burn patients a new phenomenon? *Burns* 2004; 30:464–466
 30. Saffle JI: The phenomenon of “fluid creep” in acute burn resuscitation. *J Burn Care Res* 2007; 28:382–395
 31. Wanek SM, Wolf SE, Salinas J, et al: Modern resuscitation practice in severe burns: Over-resuscitation and fluid creep. *J Burn Care Rehabil* 2006; 27:S129